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ARGILLIC HORIZONS IN SANDY SOILS OF THE SAHEL, WEST AFRICA[1]

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RESUME

Dans le cadre d'un inventaire des ressources du sol du centre sahélien de l'ICRISAT, près de Niamey (Niger), cinq profils ont été décrits et échantillonnés. Le pourcentage en argile des sols varie de 29 à 13 % et les argiles se dispersent parfaitement dans l'eau. Des argiles illuviées ont été identifiées sur le terrain dans tous les profils, mais seuls quatre des cinq profils présentent un enrichissement en argiles suffisant dans les horizons Bt pour les qualifier d'horizons argiliques. Les observations micromorphologiques montrent un accroissement de l'épaisseur et de l'abondance des revêtements des horizons A aux horizons Bt. L'observation au M.E.B. d'arangements non perturbés met en évidence la plus grande abondance de ponts entre les grains du squelette dans les horizons Bt que dans les horizons A et C. Les ponts intergrains sont aussi plus abondants dans les horizons Bt des sols identifiés sur le terrain comme ayant un horizon argilique que ceux sans horizon argilique. La forte proportion d'argile dispersable dans l'eau semble favoriser le ruissellement et l'érosion en surface, entrainant la formation de croûtes superficielles et diminuant l'infiltration de l'eau.

KEY-WORDS :
Argilic horizons - SEM - Sahel - Niger.

INTRODUCTION

Many soils in the Sahel bioclimatic zone are sandy, highly weathered, and low in native fertilty. In these sandy soils, argillic horizons are often difficult to identify, though they can have significant impact on soil management and crop response. However, many of the argillic horizons in this region are weakly expressed, and difficult to detect in the field. Thus, the objectives of this study were to (i) document the presence of argillic horizons in sandy soils of the Sahel and (ii) present implications of argillic horizons on soil management in the area.

MATERIALS AND METHODS

The soil in this study were sampled from the ICRISAT Sahelian Center near Niamey, Niger (Fig. 1) (WEST et al., 1984). Details concerning climate, parent materials, and topography are given in the soil survey of this center (WEST et al., 1984). Field and laboratory methods used to describe, sample and characterize the soils are also described in this report.

Zero point of charge (ZPC) was determined for selected samples from potentiometric titration curves by a method similar to that described by VAN RAIJ and PEECH (1972). Oriented clods from each major horizon were impregnated with a polyester resin-acetone solution for thin-section preparation. Iron-oxides were removed from thin-section with a citrate-dithionite-bicarbonate solution (BULLOCK et al., 1975).

The 0.25 to 0.50 mm sand fraction was evaluated by scanning electron microscopy (SEM). These sands were subjected to the following treatments : (i) no treatment, (ii) water dispersion, (iii) calgon dispersion, and (iv) calgon dispersion after Fe removal with Na citrate-Na dithionite (SOIL SURVEY STAFF, 1972). These treatments were on separate subsamples, not sequential. Additionally, undisturbed fragments of major horizons were observed by SEM to evaluate natural soil fabrics. Selected thin-sections were subjected to mircroprobe analysis to document composition of fabric components.

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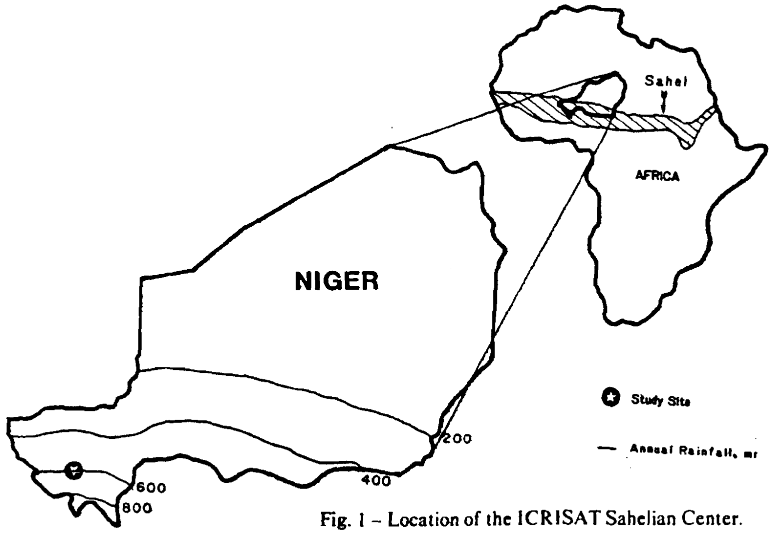

Fig. 1 – Location of the ICRISAT Sahelian Center.

Soil	Classification
Dayobu	Ustoxic Quartzipsamment; isohyperthemic, coated
Gagani	Petroferric Haplustult; loamy, siliceous, isohyperthermic, shallow
Labucheri	Psammentic Paleustalf; sandy, siliceous, isohyperthermic
Tondi	Petroferric Haplustult; sandy, siliceous, isohyperthermic
Zogoti	Psammentic Paleustalf; sandy, siliceous, isohyperthermic

Table 1 – Classification of the soils according to Soil Taxonomy (SOIL SURVEY STAFF, 1975).

		Particle size distribution (mm)						
				clay				
		sand	silt	fine	total	water	pH	
		2–	0.05–	<	<	dispersed*		
	Depth	0.05	0.002	0.0002	0.02	<0.002	H_2O	KCl
Horizon	cm	%						
				Dayobu				
A1	0–15	92.5	3.0	2.1	4.5	4.3	5.1	4.0
A2	15–27	91.7	3.2	2.9	5.1	4.1	4.9	3.9
Bt1	27–44	92.1	3.2	2.6	4.7	3.7	4.8	3.9
Bw	80–103	92.5	3.2	1.7	4.3	3.6	4.8	4.0
BC	126–150	94.5	1.9	1.6	3.6	3.4	4.8	4.0
C	173–200	94.6	2.9	2.5	2.5	2.4	4.9	4.1
				Labucheri				
A1	0–18	93.8	3.3	2.3	2.9	3.7	5.4	5.2
A2	18–30	91.0	3.8	2.7	5.3	5.6	5.6	5.0
Bt1	30–51	87.4	5.6	4.3	7.0	7.9	5.7	4.9
Bt2	51–71	85.2	4.3	5.4	10.5	10.9	5.3	4.3
Bt5	178–200	85.5	5.4	4.7	8.7	8.6	5.2	4.6
C	430–460	90.0	4.9	2.8	5.1	4.8	5.0	4.2
Btb	620–640	83.2	7.3	5.4	9.5	9.9	5.1	4.7

* Slightly higher values for water dispersible vs. electrolyte dispersible clay for some horizons in the Labucheri pedon are within the experimental error of determination.

Table 2 – Physical and chemical properties of the Dayobu and Labucheri pedons.

RESULTS AND DISCUSSION

The classification of the five soils sampled on the Sahelian Center is given in Table 1. Morphological, physical, chemical, and mineralogical properties of the soils are discussed in WEST et al. (1984).

Evidence for Argillic Horizons

Morphological and Textural Evidence

All soils mapped on the Sahelian Center had morphological evidence of translocated clay. However, the magnitude of the clay increase between A and Bt horizons from the Dayobu pedon (Tab. 2) is insufficient to meet the requirements of an argillic horizon. Morphological evidence for argillic horizons includes : (i) higher clay contents in the Bt horizons than in either A or C horizons, (ii) field identification of thin bridges of clay between sand grains, (iii) redder colors in Bt horizons of soils with argillic horizons than Bt horizons from soils without argillic horizons, and (iv) the topography of the upper boundary of the argillic horizon conforms to the surface topography.

Mechanisms other than translocation could account for the textural differentiation in these soils. However, the data do not support alternate mechanisms in that : (i) total and fine clay would not be expected to increase to a maximum in the argillic horizon and decrease in C horizons, (ii) clay–free total sand and silt and subseparates of these fractions are relatively constant with depth, and (iii) there is no systematic change in sand and silt subseparate ratios. The plaucity of weatherable minerals in the parent sands negates clay neoformation as a mechanism for textural differentiation in these soils.

Most of the clay in these soils is water dispersible (Tab. 2) which provides a mechanism for dispersion of the clay in surface horizons and translocation to subjacent horizons. This is not attributed to dispersion by Na because ESP is negligible (WEST et al., 1984). However, the large difference between the ZPC and pH of these soils in water (ZPC – 2.8 to 3.2 ; pH – 4.3 to 5.8), their low organic carbon content, low Fe–oxide content, and low electrolyte levels favor large proportions of water–dispersible clay.

Micromorphological Evidence

The microfabric of all horizons was similar with the exception of the thickness of grain cutans. All horizons had granular related distribution with many simple packing voids (Fig. 2). Skeleton grains were subrounded to subangular and dominantly quartz. A few rounded Fe nodules with imbedded skeleton grains were also observed. Grain ferriargillans in all horizons were reddish-brown with undulic plasmic fabric (125X). Because of Fe pigmentation, extinction phenomena could not be evaluated. A and C horizons had very thin cutans, and no bridges between skeleton grains were observed. Grain cutans in Bt horizons from the Dayobu pedon (no argillic horizon) were similar in thickness to those in a A and C horizons, and only rarely were bridges observed between skeleton grains. The Bt horizons from soils with argillic horizons had thicker grain cutans and had occasional clay bridges between skeleton grains (Fig. 2).

After Fe removal, the very–thin grain cutans in A and C horizons showed moderate orientation with a mottled extinction pattern. However, extinction patterns at grain contacts were independent for each grain. Thicker cutans and bridges in Bt horizons were isotic to indeterminant, but continuity of extinction patterns across the bridges could be seen in a few instances. Both types of cutans had low birefringence. Because thin, moderately oriented cutans were present in C horizons and were not optically continuous between grains, it is postulated that they were a component of the parent eolian sands. The thicker cutans and bridges are interpreted to be illuvial clay that has been translocated from superjacent horizons.

The "grainy" appearance of many of the ferriargillans suggests that at least part of the clay may have been translocated as Fe–oxide rich, flocculated colloids (WANG and MICKEAGUE 1982). However, the high water dispersibility of the clay implies that translocation is occuring with the clay in a dispersed state. The "grainy" appearance of the cutans may be the result of disruption upon drying, either naturally or during sample preparation (ESWARAN, 1971).

SEM Evidence

Untreated grains from all horizons have plasma coatings which were completely removed with water dispersion. Chemical dispersion treatments did not remove additional material (Fig. 3). Complete removal of plasma from the grains with water dispersion supports the high water dispersibility of the clay.

Uncoated grains are severely pitted, and such pitting of quartz grains has been reported to increase with soil age (DOUGLAS and PLATT, 1977 ; GLASSMANN and KLING, 1980). However, in these soils, the pitting may be a relict feature from past climatic or depositional episodes. Quartz in the fine clay fraction suggests that the contemporaneous environment does not favor desilication.

Pitted grain surfaces may be important in physically binding clay on the quartz surfaces. A chemisorption mechanism for stabilizing clay on the grain surfaces seems improbable unless the quartz has a disrupted surface layer to provide bonding sites between the quartz and the clay

(RIBAULT, 1971). In the absence of direct evidence for chemisorption, a physical bonding mechanism seems more plausible. Upon desiccation, clay particles are deposited along surface pit walls and physically anchored to grain surfaces. Physical versus chemical adhesive mechanisms favor the large proportion of water-dispersible clay.

The granular fabric of these soils can also be seen with SEM (Fig. 3). Plasma bridges between skeleton grains were observed in Bt horizons from all of the soils but were lacking in A and C horizons. Clay bridges were thicker and more abundant in Bt horizons from soils with argillic horizons than in Bt horizons from the Dayobu pedon. Microprobe analysis indicated the bridges to be dominantly Si and Al confirming their identification as clay.

Importance of clay dispersion and argillic horizons to soil management

Because of the high dispersibility of the clay in these soils, rainfall entering the soil will tend to disperse clay in surface horizons. This dispersion coupled with low organic carbon contents results in surface horizons with little cohesion. Thus, structure is weak in these horizons, and the soils are highly wind and water erodable. Movement of the dispersed clay to subsoil horizons increases clay content in these horizons which increases subsoil water and nutrient retention and slows the loss of bases and mobile fertilizer nutrients.

CONCLUSIONS

Sandy soils in this region have argillic horizons as indicated by morphology, particle-size distribution, micromorphology, and SEM evaluation. Argillic horizons in these soils may be, in part, relict features of more pluvial paleoclimates. It is improbable that the thick sola of these soils (>2 m) have developed entirely under the present semi-arid climate. However, the dispersibility of the clay provides a mechanism for easy translocation and suggests that clay translocation is occurring under the present climate. Clay dispersibility and the presence of argillic horizons also help to explain behavior of these soils when used for crop production and must be considered when evaluating soil management practices. Micromorphology and submicroscopy can be valuable tools in aiding the understanding of soil genesis and behavior.

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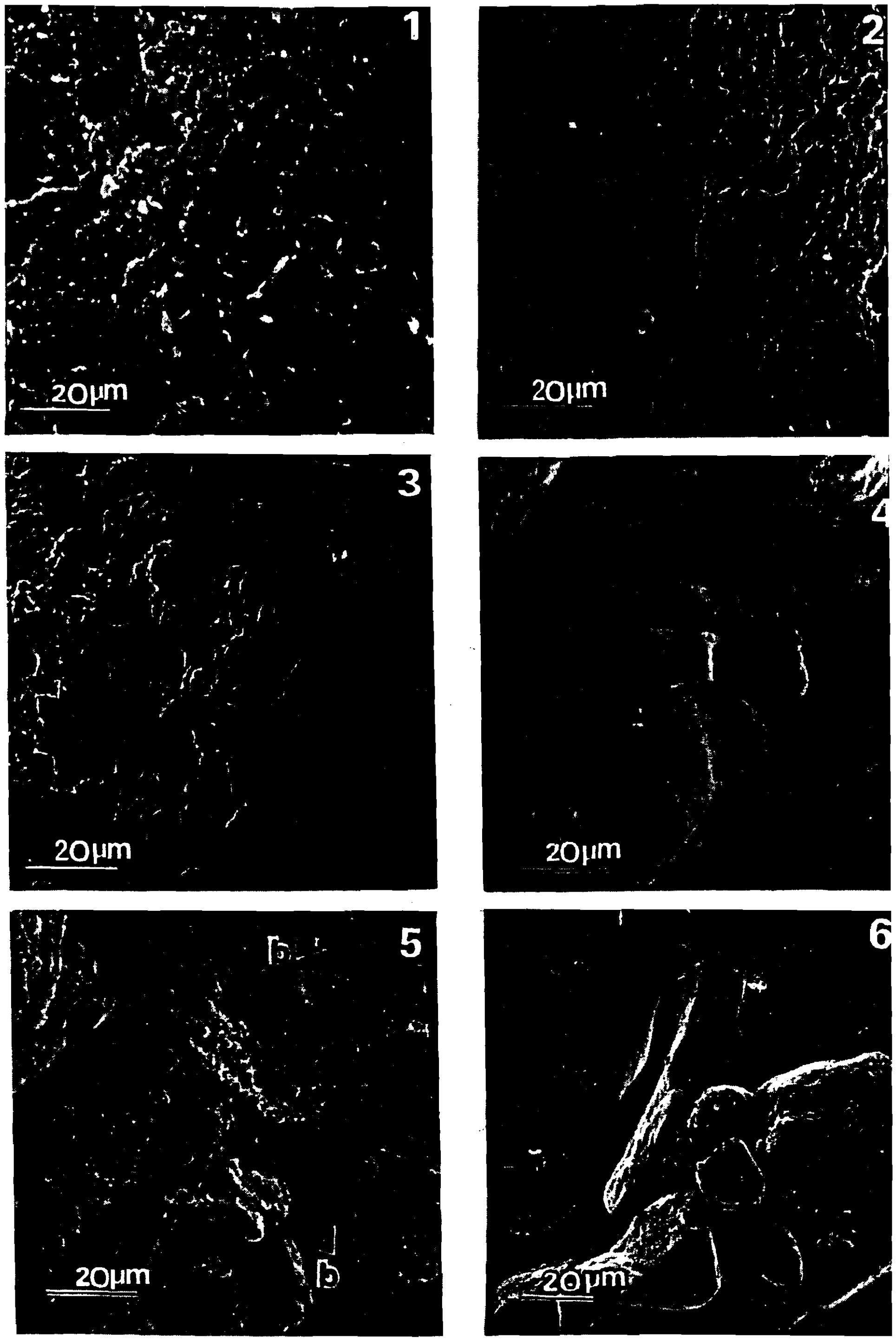

Fig. 3 – SEM micrographs : 1, 2, and 3 are medium sand grains.
1. no treatment ; 2. water dispersion ; 3. calgon dispersion. 4, 5, and 6 are undisturbed fabrics. 4. A horizon, Labucheri pedon ; 5. Bt2 horizon, Labucheri pedon ; 6. C horizon, Dayobu pedon.
b = clay bridge

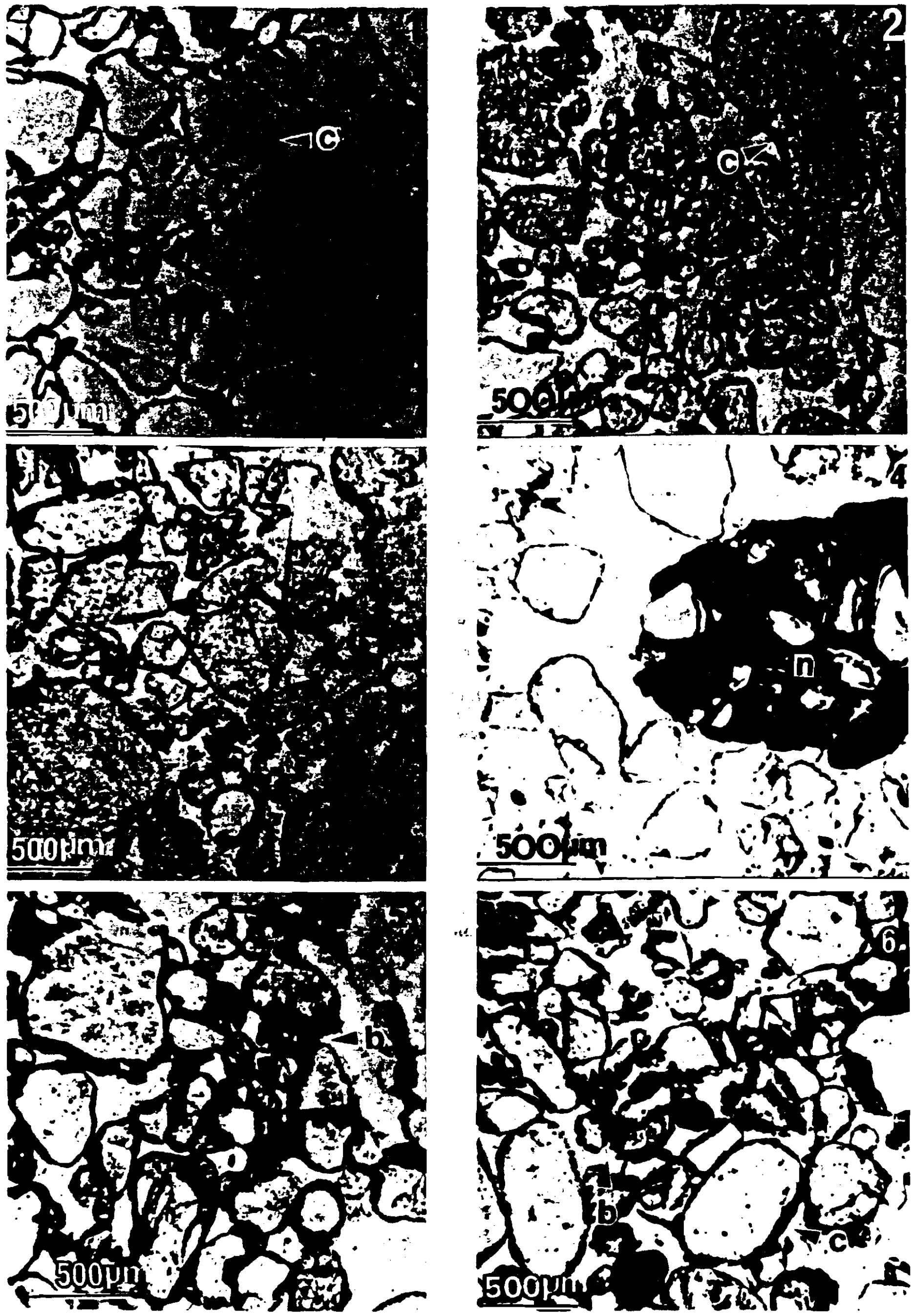

Fig. 2 – Thin-section micrographs (P.P.L.)
Dayobu pedon : 1. A horizon, 2. Bt2 horizon, 3. C horizon.
Labucheri pedon : 4. A horizon, 5. Bt2 horizon, 6. Bt5 horizon.
c. cutan ; b = clay bridge ; n = nodule

Fig. 3 – Six examples, illustrating the general trends. All soils are in coarse textured parent materials :
1. Holocene soil with insepic plasmic fabric and thin discontinuous ferri–argillans ; X.P.L. (Po plain).
2. Early Middle Pleistocene soil : rounded pedorelicts, embedded in reddish brown S–matrix with common ferri–argillans, partly decomposed ; P.L. (Po plain).
3. Early Pleistocene–Late Tertiary buried paleosol, with undulic to isotic fabric, lacking illuvial cutans, X.P.L. (Po plain).
4. Upper Pleistocene (Eemian) soil with insepic plasmic fabric and common simple channel ferri– argillans, X.P.L. (Central Italy, Prov. Grosseto).
5. Middle–Pleistocene soil with skel–masepic plasmic fabric and abundant compound ferri–argillans, which have been strongly disturbed by stress and partly incorporated in the matrix, X.P.L. (Central Italy, Prov. Grosseto).
6. Early Pleistocene soil with isotic plasmic fabric and few channel ferri–argillans, crossed nicols, 1 (Central, Italy, Prov. Latina).